Impact of Different Weft Materials and Washing Treatments on Moisture Management Characteristics of Denim

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ABSTRACT
The aim of this study was to investigate the effects of different types of weft yarn materials and washing treatments on the moisture management properties of denim fabrics. Fabrics were developed with five different types of weft yarns made of cotton, polyester, spun polypropylene, air-textured polypropylene and stuffer-box crimped polypropylene. In all cases 100% cotton yarn was used as warp. Samples from each fabric were subjected to 10 diverse types of washing/finishing treatments and the treated samples were tested for dissimilar moisture management indices on an SDL Atlas moisture management tester. The statistical analyses of the test data show that the effect of different types of weft yarns and washing treatments is significant. Based on the results of this study, denim fabrics can be developed with enhanced moisture management properties.

Keywords: moisture management, denim, weft variation, garment washing

INTRODUCTION
When water is dropped on the surface of any textile material it moves in multi directions. Its movement depends upon the chemical and physical nature of the textile material. The ability to control the movement of moisture is called moisture management of textile material [Hu 2005].

Clothing comfort is one of the basic needs of the wearer. It depends upon the thermo- physiological characteristics of the textile material. In addition to tactile feeling, heat and moisture transfer are key factors, which contribute to clothing comfort perception. Moreover, air and water-vapor permeability properties of clothing also have a significant influence on comfort characteristics. There is a significant difference in thermal properties of water and textiles. One of the most important factors is thermal conductivity. Water has 0.6 ($Wm^{-1}K^{-1}$), which is quite higher than textile materials. Textile materials may be hydrophobic or hydrophilic in nature. Many complexities are attached with the adsorption and absorption processes. Overall, adsorption and absorption of water in textiles create a big change in their thermal characteristics. This change leads to change in their thermal and moisture sensation and overall comfort properties. There is a strong correlation between moisture management properties of a fabric and its final comfort perception (Amrit, 2007; Barker, 2006; Hes & Martins, 1993; Satsumoto, Murayama, & Takeuchi, 2009; Kandjov, 1999; She & Kong, 2000; Suleiman, 2006).

This study investigated the moisture management properties of denim woven with a constant warp and five different weft yarns and subjecting the samples to 10 different types of washing processes. The specific objectives of this study were as follows: (a) to investigate the effect of different weft yarn materials on the moisture management properties of denim fabrics and (b) to investigate the effect of different washing treatments on the moisture management properties of denim fabrics.

WATER VAPOR TRANSPORT MECHNAISM THROUGH NOVEL AND TRADITIONAL DENIM
Traditional denim is composed of 100 % cotton and has the ability to absorb moisture from the human skin and can transport it to the outer side following Fick's law. In the case when the surface which touches the human skin is partially composed of polypropylene or polyester, which is hydrophobic in nature, moisture transfer from inner side to outside becomes quicker. In the case of denim made of 100% cotton, there are more chances that moisture will accumulate between the human skin and the inner side of the denim, and the difference in moisture percentage between human body and the microclimate will decrease, which is the driving force for the transfer of moisture from inner climate to outer climate. Nevertheless, in the case of the inner side partially covered by manufactured fibers, the amount of moisture absorbed will be less. In addition,

manufactured fibers will provide a channel for the transfer of the moisture. Moreover, the presence of 100% material on the surface (outer side) will absorb moisture from the inner side. Exposure of the outer side to the external environment will boost transfer of moisture. The most common sweat shirts are made by using a polyester-cotton blend as the inner side yarn and an outer yarn of 100% cotton. Gunesoglu, et al (2005) tested knitted fabrics having different composition of cotton and polyester for loop and finally concluded that fleece made by using polyester-cotton (87:13) for loop has the lowest thermal absorptivity, an indicator of warm and cool effect, under wet processing conditions, which shows that touching of hydrophobic and hydroscopic material with human skin helps in keeping the skin dry and provides support in transport of moisture from inner side to the outer side.

MATERIALS AND METHOD

Specifications of five varied denim fabrics used in this study are given in *Table I*. Samples from all five fabrics were subjected to 10 distinctive washing treatments. A description of specialty chemicals used in washing treatments is given in *Table II*. Hydrogen Peroxide and Acetic Acid used were of commercial grade. A short description of all washing treatments is given in *Table III*.

All the treated fabric samples were tested on an SDL Atlas Moisture Management Tester according to AATCC Test Method 195-2009. The Moisture Management Tester (MMT) was developed by Yi Li, Qing Wen Song and Jun Yan Hu to measure the flow of water when drops of water touch the surface of fabric (Hu, Li, Yeung, Wong, & Xu, 2005). The instrument gives different indices, which quantify the movement of water in different directions in a textile material. The fabric side that was used as 'top' during testing in this study refers to that side of the denim fabric on which the weft or filling yarns are predominant. This is the side of denim fabric, which would come into contact with skin when the denim garment is worn. The 'bottom' fabric side had predominantly the cotton warp yarns exposed, which were held constant in the study while the weft yarns were varied from cotton to polyester, spun polypropylene, air-textured polypropylene and stuffer-box crimped polypropylene.

TABLE I. Specifications of denim fabrics used in this study.

No.	Warp Yarn Material	Weft Yarn Material	Warp linear density (tex)	Weft Linear Density (tex)	Fabric Weave	Fabric weight (gmm^{-2})
D1	Cotton	Spun polypropylene (SPP)	49.25	54.00	3/1 Z	239
D2	Cotton	Stuffer-box crimped polypropylene (SBC PP)	49.25	38.00	3/1 Z	224
D3	Cotton	Air-textured polypropylene (AT PP)	49.25	44.0	3/1 Z	229
D4	Cotton	Cotton (CO)	49.25	49.0	3/1 Z	230
D5	Cotton	Polyester (PES)	49.25	37.0	3/1 Z	231

TABLE II. Specialty chemicals used in denim washing.

No.	Name	Description	Manufacturer/Supplier
1	Lenitol EHDS	Amylase enzyme	CHT, GMBH
2	Sltafon D	Wetting agent	Mukashi Pakistan
3	Forelase SWGR	Cellulase enzyme	CHT, GMBH
4	Fortress ECO2	Anti back-staining agent	Mukashi Pakistan
5	Belfasin OET	Cationic softener	Cognis
6	Rucofin GWE	Silicon softener	Rudolf Chemical
7	RucoStar EEE	Water repellent chemical	Rudolf chemical
8	RUCO PUR SEC	Quick Dry chemical	Rudolf chemical

TABLE III. Description of different denim washing treatments.

No.	Type	Description
W1	Desizing + Rinsing (D)	Desizing was done using Lenitol EHDS (0.75ml/l), Sltafon D (0.375 ml/l) and ECO2 (0.5 ml/l) at 60°C for 15 min. Desizing was followed by rinsing with water at ambient temperature.
W2	Desizing + Cellulase Treatment (D+C)	Desizing was done as in W1 followed by treatment with Forelase SWGR (0.75 g/l) and ECO2 (0.5 ml/l) at 60°C for 15 min. and then rinsing with water at ambient temperature.
W3	Desizing + Cellulase Treatment + H_2O_2Treatment (D+C+B)	Desizing and Cellulase treatment was done as in W2 followed by treatment with H_2O_2 (4 g/l) at 60°C for 5 min. and then rinsing with water at ambient temperature.
W4	Desizing + H_2O_2Treatment + silicone softener (D+B+SS)	Desizing was done as in W1 followed by treatment with H_2O_2 (4 g/l) at 60°C for 5 min. and then treatment with Rucofin GWE (3.75 g/l).
W5	Desizing + H_2O_2Treatment (D+B)	Desizing was done as in W1 followed by treatment with H_2O_2 (4 g/l) at 60°C for 5 min. and then rinsing with water at ambient temperature.
W6	Desizing + H_2O_2Treatment + Quick-dry finish (D+B+QD)	Desizing and H_2O_2 treatment was done as in W5 followed by treatment with RUCO PUR SEC (3.75 g/l).
W7	Desizing + H_2O_2Treatment + Cationic Softener (D+B+CS)	Desizing and H_2O_2 treatment was done as in W5 followed by treatment with Belfasin OET (4 g/l).
W8	Desizing + Cellulase Treatment + Pumice Stones (D+C+St)	Desizing and Cellulose treatment was done as in W2 in the presence of pumice stones.
W9	Desizing + H_2O_2Treatment + Water-repellent finish (D+B+WR)	Desizing and H_2O_2 treatment was done as in W5 followed by treatment with RucoStar EEE (4 g/l).
W10	Desizing + Peach Finish[1] (D+P)	Desizing and rinsing was carried out as W1 followed by peaching on brushed peaching machine.

[1] Peaching is process in which fabric is rubbed against some brushes or in some case against some sand papers to have a protruding (outstanding) fibers of very small height to get a soft look like skin of Peach fruit. It is also called sueding.

RESULTS AND DISCUSSION

Effect of Different Types of Washing Treatments and Weft Yarns on Fabric Wetting Time

Table IV gives two-way analysis of variance (ANOVA) results for the effect of type of washing treatments and weft yarns on fabric wetting time. It can be observed from *Table IV* that the effect of type of washing treatment is significant on wetting time of the fabrics' top and bottom sides (P = 0.004 & 0.000). The 'top' in this study refers to that side of the denim fabrics where weft yarns are pre-dominant while 'bottom' refers to that side where warp yarns are predominantly exposed. During moisture management testing, the water drop was allowed to fall first on the 'top' surface wherefrom it spread outwards as well as penetrated towards the bottom side of the fabric. The effect of type of weft yarn was not found to be significant on fabric wetting time.

TABLE IV. Two-way ANOVA for effect of type of washing treatments and weft yarns on fabric wetting time.

	Source	DF	SS	MS	F	P
Top Wetting Time (WTt)	Type of Washing Treatment	9	707.14	78.5714	3.47	0.004
	Type of Weft Yarn	4	127.44	31.8604	1.41	0.251
	Error	36	815.11	22.6419		
	Total	49	1649.69			
	R-sq = 50.59%					
Bottom Wetting Time (WTb)	Type of Washing Treatment	9	67671.3	7519.04	14.82	0.000
	Type of Weft Yarn	4	1336.0	333.99	0.66	0.625
	Error	36	18262.1	507.28		
	Total	49	87269.3			
	R-sq = 79.06%					

Effect of different types of washing treatments on fabric wetting time on the top and bottom sides is shown in *Figure 1 and 2* respectively. It is obvious that the top wetting time is shorter as compared to the bottom wetting time. All fabric tops wet fairly quickly except that was subjected to peaching (D+P) finish. Peaching was done on the top fabric side only where the hydrophobic polypropylene and polyester fibers are predominant in all the fabrics except one that had cotton weft yarns. The short protruding fibers, resulted by peaching, may have caused interference in the wetting of the fabric top. *Figure 2* shows that bottom wetting time is longest in the fabric that was treated with water repellent finish (WR), which is obviously due to hydrophobic nature of the finish.

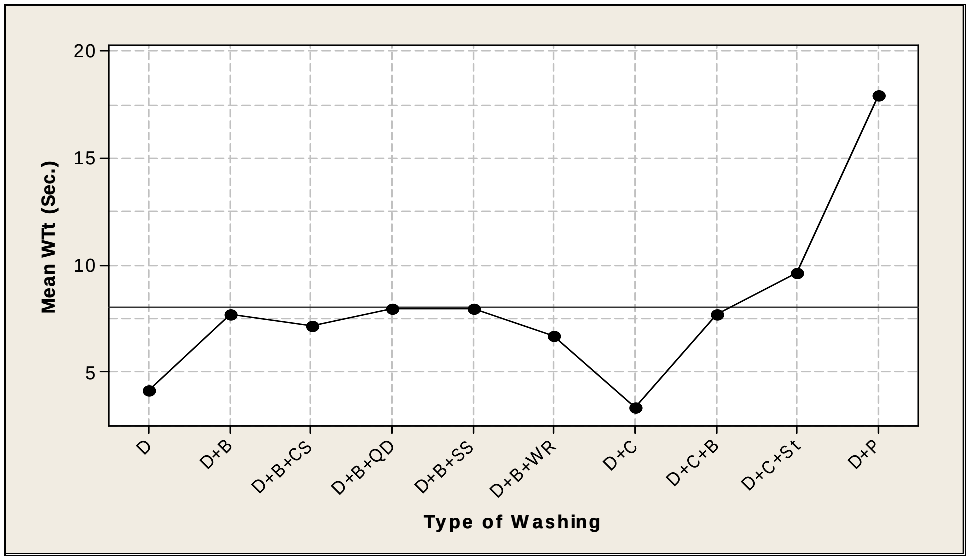

FIGURE 1. Effect of different types of washing treatments on top wetting time.

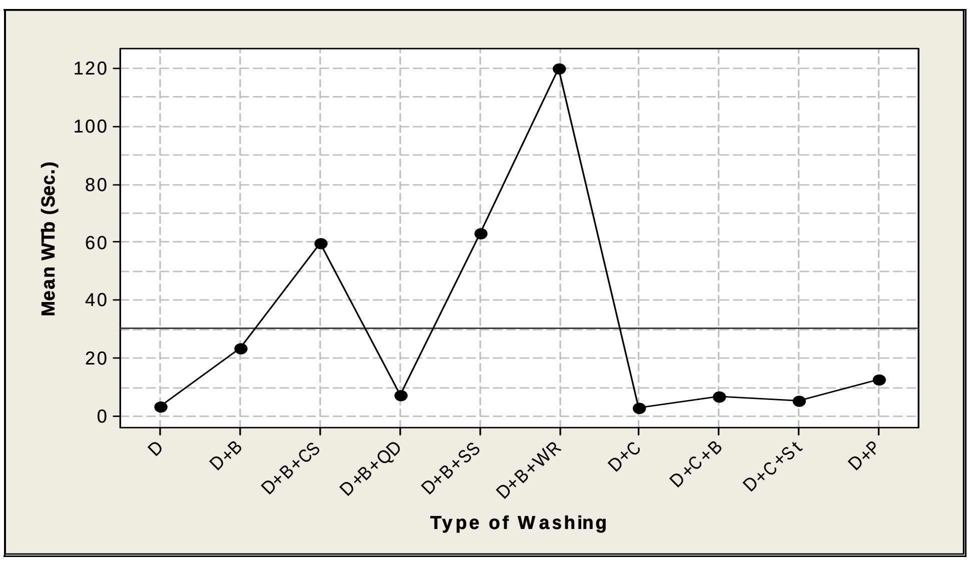

FIGURE 2. Effect of different types of washing treatments on bottom wetting time.

Effect of Different Types of Washing Treatments and Weft Yarns on Maximum Wetted Radius of the Fabric

The effect of different type of washing treatments and weft yarns on the top and bottom maximum wetted radii of the fabric is given as a two-way ANOVA in *Table V*. It can be observed that the effect of type of washing is significant on both the top and bottom maximum wetted radii (P = 0.000). However the effect of different types of weft yarns is only significant on the bottom wetted radius (P = 0.016) and not on the top maximum wetted radius (P = 0.151).

TABLE V. Two-way ANOVA for effect of type of washing treatments and weft yarns on maximum wetted radii of the fabric.

	Source	DF	SS	MS	F	P
	Type of Washing Treatment	9	3150.5	350.056	18.89	0.000
Top Maximum	Type of Weft Yarn	4	133.0	33.250	1.79	0.151
Wetted Radius	Error	36	667.0	18.528		
(MWRt)	Total	49	3950.5			
	R-sq = 83.12%					
Bottom	Type of Washing Treatment	9	5348	594.222	40.21	0.000
Maximum	Type of Weft Yarn	4	208	52.000	3.52	0.016
Wetted Radius	Error	36	538	14.778		
(MWRb)	Total	49	6088			
	R-sq = 91.26%					

Figure 3 and 4 illustrate the effect of different washing treatments on top and bottom maximum wetted radii, respectively. It is clear that treatments containing hydrophobic finishes such as cationic softener (CS), silicon softener (SS) and water-repellent (WR) resulted in poor water spreading along with peached fabric where the tiny protruding fibers may also have hindered the spreading phenomenon.

The effect of different types of weft yarns on a bottom maximum wetted radius is depicted in *Figure 5*. It can be observed that the spreading is higher in case of hydrophobic weft polypropylene and polyester yarns as compared to hydrophilic cotton weft. It follows from the results that having hydrophobic yarns on the inner garment side and hydrophilic yarns on the outer garment side will result in higher perspiration spreading on the outer side which will also help in its quicker evaporation because of larger wetted radius.

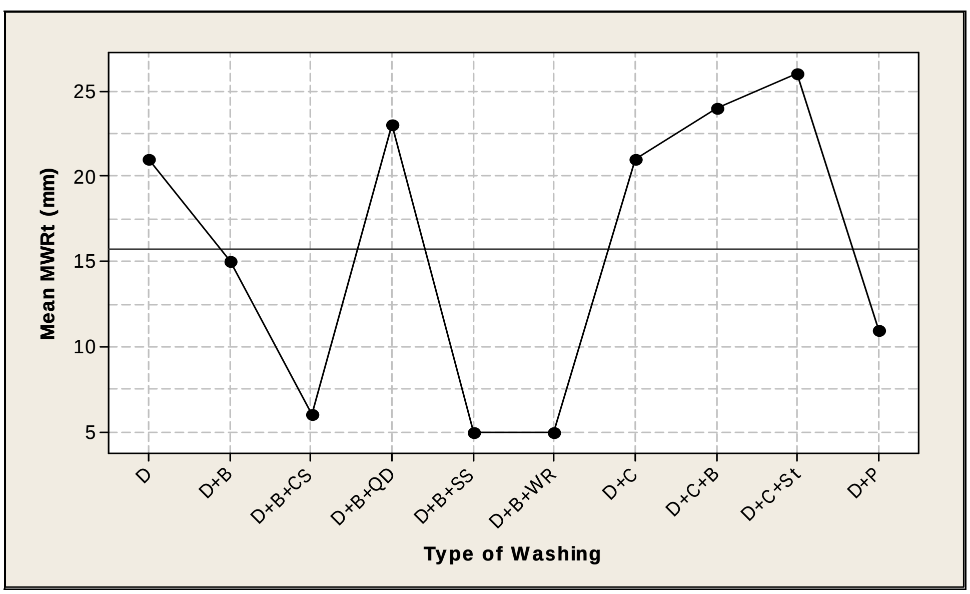

FIGURE 3. Effect of different types of washing treatments on top max. Wetted radius..

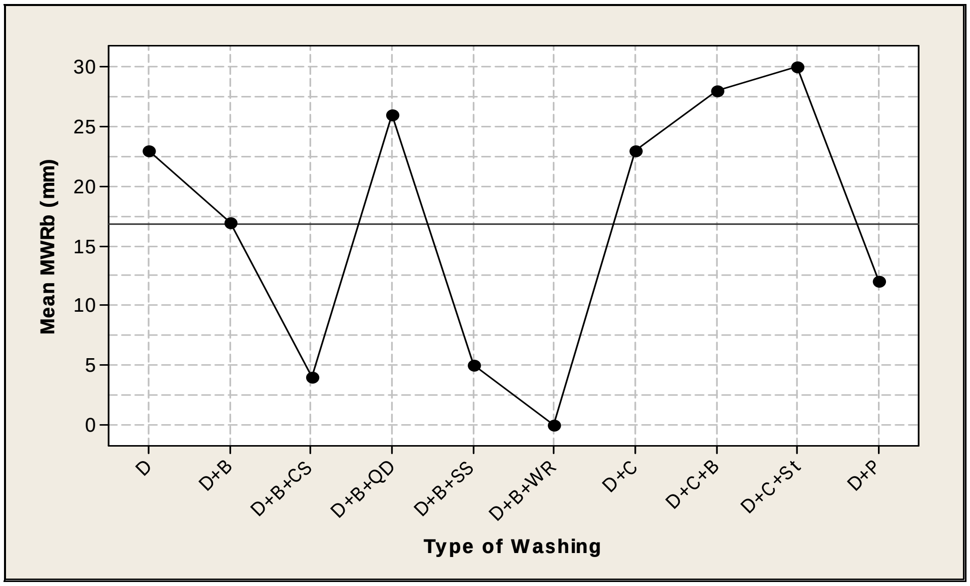

FIGURE 4. Effect of different types washing treatments on bottom max. Wetted radius.

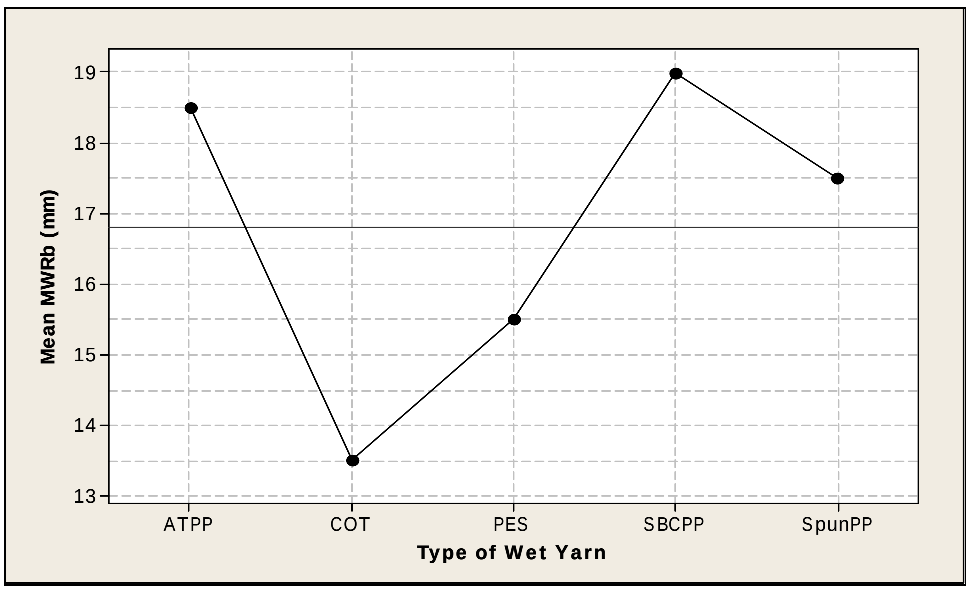

FIGURE 5. Effect of different types of weft yarns on bottom max. Wetted radius.

Effect of Different Types of Washing Treatments and Weft Yarns on Water Spreading Speed

Two-way ANOVA results for the effect of different washing treatments and weft yarns on water spreading speed on the top and bottom fabric sides is given in *Table VI*. Although the effect of type of washing treatment was found to be significant on both top and bottom spreading speed (P = 0.000), the effect of type of weft yarn was only found significant on the bottom fabric side (P = 0.009). The effect of type of washing treatment on top and bottom spreading speeds depicted in *Figure 6 and 7* shows similar trends as that of top and bottom maximum wetted radii. The same is true for the effect of different weft yarns on water spreading speed at the bottom fabric side (*Figure 8*), where the spreading speed is higher in case of hydrophobic weft yarns at the top fabric side and hydrophilic cotton yarn at the bottom fabric side.

TABLE VI. Two-way ANOVA for effect of type of washing treatments and weft yarns on water spreading speed.

	Source	DF	SS	MS	F	P
Top Spreading Speed (SSt)	Type of Washing Treatment	9	110.705	12.3006	27.37	0.000
	Type of Weft Yarn	4	3.005	0.7514	1.67	0.178
	Error	36	16.178	0.4494		
	Total	49	129.888			
	R-sq = 87.55%					
Bottom Spreading Speed (SSb)	Type of Washing Treatment	9	204.795	22.7550	45.84	0.000
	Type of Weft Yarn	4	7.906	1.9764	3.98	0.009
	Error	36	17.872	0.4964		
	Total	49	230.573			
	R-sq = 92.25%					

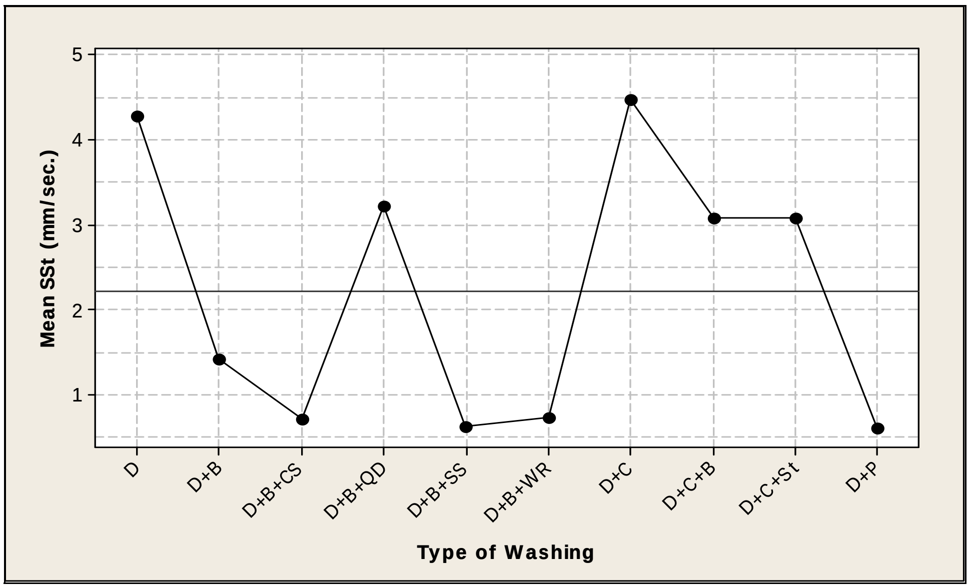

FIGURE 6. Effect of different types of washing treatments on top spreading speed.

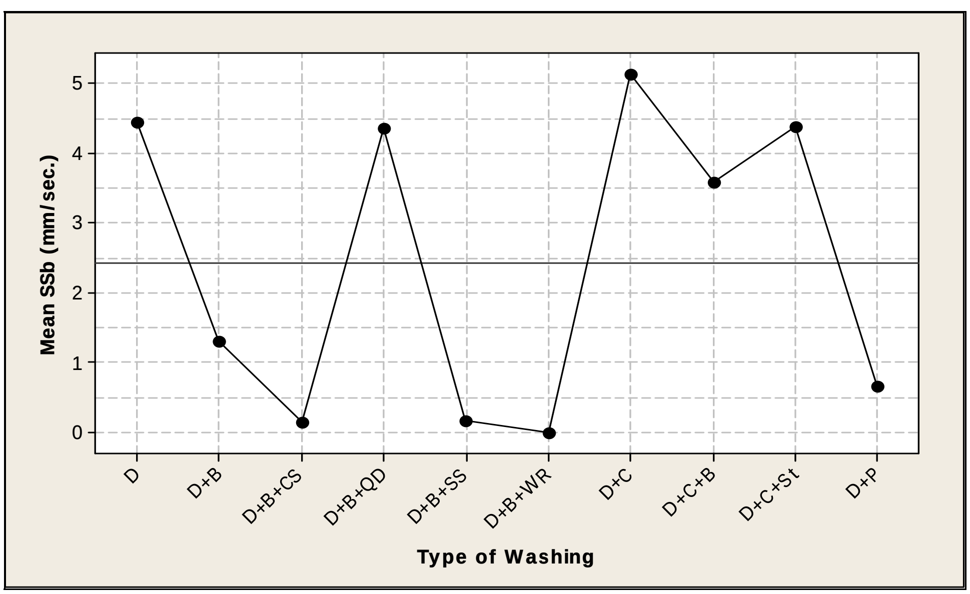

FIGURE 7. Effect of different types of washing treatments on bottom spreading speed.

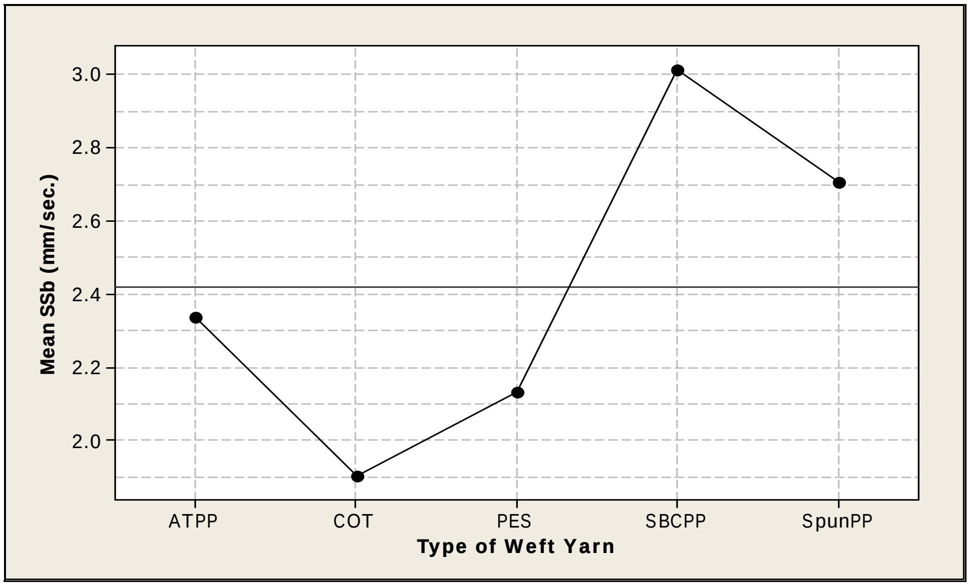

FIGURE 8. Effect of different types of weft yarns on bottom spreading speed.

Effect of Different Types of Washing Treatments and Weft Yarns on Accumulative One-Way Transport (AOWT)

Accumulative one-way transport is a measure of the difference between the areas of the liquid moisture content curves of the top and bottom surfaces of a specimen with respect to time. *Table VII* gives the two-way analysis of variance (ANOVA) results of accumulative one-way transport (AOWT) of fabric samples versus different types of washing treatments and weft yarns. It can be observed that the effect of type of wash (P = 0.000) and the type of weft (P = 0.013) is statistically significant. This means that different types of washing treatments and weft yarns result in significantly different values of overall moisture management capacity of fabrics. For the AOWT data, R-sq equals 78.10%, which gives the percentage variation in AOWT that can be explained by the type of washing and the weft changes.

TABLE VII. Two-way ANOVA for effect of type of washing treatments and weft yarns on accumulative one-way transport.

Source	DF	SS	MS	F	P
Type of Washing Treatment	9	7797893	866433	12.62	0.000
Type of Weft Yarn	4	1011407	252852	3.68	0.013
Error	36	2470908	68636		
Total	49	11280208			

A main effect plot for effect of type of washing on AOWT is given in *Figure 9*. It is evident that accumulative one-way transport of moisture is maximum in case Spun Polypropylene weft yarn, followed by Air-textured Polypropylene (ATPP), Stuffer-box Crimped Polypropylene (SBCPP), Polyester (PES) and Cotton (COT) weft yarn. It follows from the results that denim fabrics with weft yarns made from polypropylene will keep the skin of the wearer dry by transporting the perspiration towards the outer side of the fabric which is away from the skin. This is because in denim, the fabric side which comes in contact with the skin has predominantly exposed weft yarns and the side which is away from the wearer has predominantly exposed warp yarns. Hence a fabric with good accumulative one-way transport from the inner fabric side to the outer side will offer good sweat management to the wearer.

The effect of different types of washing on AOWT is given in *Figure 10*. It is clear that desizing (D), desizing + cellulose treatment (D+C), desizing + cellulose treatment + bleaching (D+C+B), desizing + celllulase treatment + stone washing (D+C+St), desizing + quick-dry finish (D+QD) and desizing + peaching (D+P) resulted in good accumulative one-way transport of moisture from the treated fabric, whereas washing treatments containing water repellent finish (WR), silicon softener (SS) and cationic softener (CS) resulted in poor AOWT, which can be explained by the hydrophobic nature of these finishes. *Figure 10* further elaborates that desized, bleached and having water repellant finish has the lowest value of AOWT. It may be due to the influence of water repellent chemicals on the surface of the fabric.

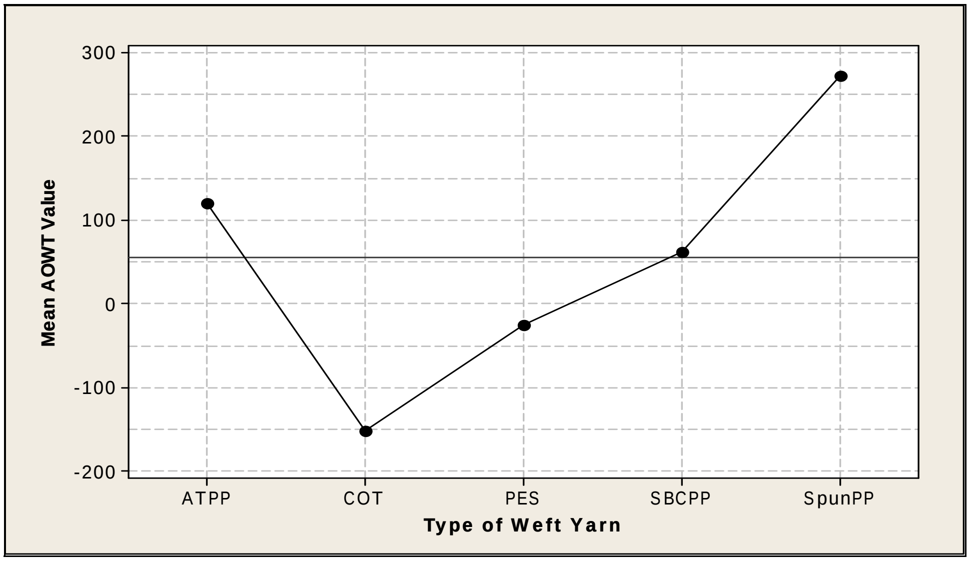

FIGURE 9. Effect of different types of weft yarn on AOWT.

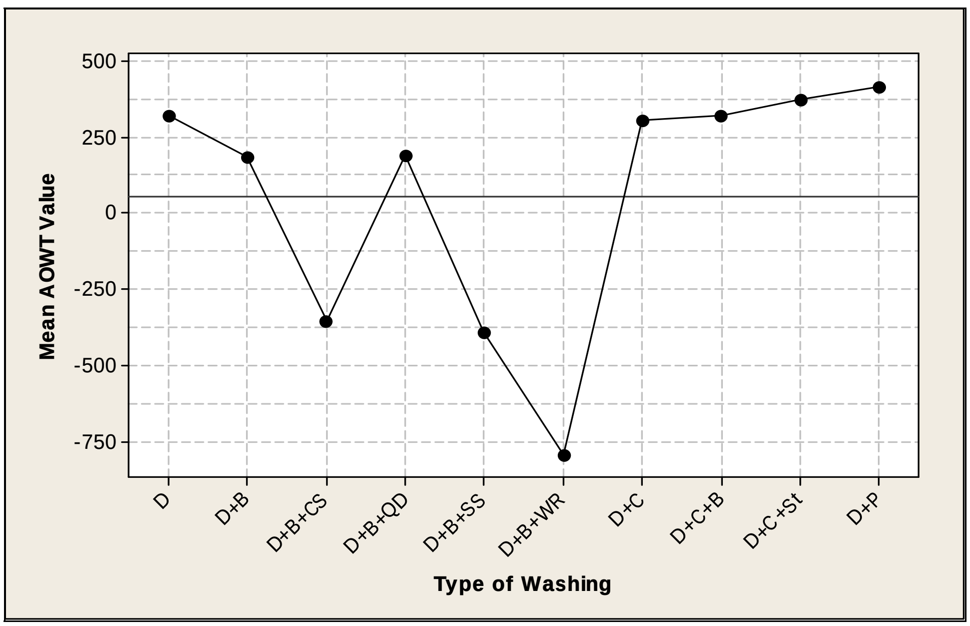

FIGURE 10. Effect of different types of washing treatment on AOWT.

<u>Effect of Different Types of Washing Treatments and Weft Yarns on Overall Moisture Management Capacity</u>

Table VIII gives the two-way analysis of variance (ANOVA) results of overall moisture management capacity (OMMC) of fabric samples versus different types of washing treatments and weft yarns. It is clear from the table that the effect of type of wash (P = 0.000) and the type of weft (P = 0.014) is statistically significant. This indicates that different types of washing treatments and weft yarns result in significantly different values of overall moisture management capacity of fabrics. For the OMMC data, R-sq equals 82.50%, which gives the percentage variation in OMMC that can be explained by the type of washing and the weft changes.

TABLE VIII. Two-way ANOVA for effect of type of washing treatments and weft yarns on OMMC.

Source	DF	SS	MS	F	P
Type of Washing Treatment	9	3.78827	0.420919	17.25	0.000
Type of Weft Yarn	4	0.35303	0.088258	3.62	0.014
Error	36	0.87834	0.024398		
Total	49	5.0164			

A main effect plot for the effect of type of washing on OMMC is given in *Figure 11*. Clearly overall moisture management capacity is maximum in case Spun Polypropylene weft yarn, followed by Air-textured Polypropylene (ATPP), Stuffer-box Crimped Polypropylene (SBCPP), Polyester (PES) and Cotton (COT) weft yarn.

The effect of different types of washing on OMCC is given in *Figure 12*. It is clear that desizing (D), desizing + cellulose treatment (D+C), desizing + cellulose treatment + bleaching (D+C+B) and desizing + celllulase treatment + stone washing (D+C+St) resulted in good overall moisture management capacity of the treated fabric, whereas washing treatments containing water repellent finish (WR), silicon softener (SS) and cationic softener (CS) resulted in poor OMMC, which can be explained by the hydrophobic nature of these finishes. The OMMC of fabrics treated with the quick dry finish (QD) was also found to be above average followed by that of the desized + peached (D+P) fabrics.

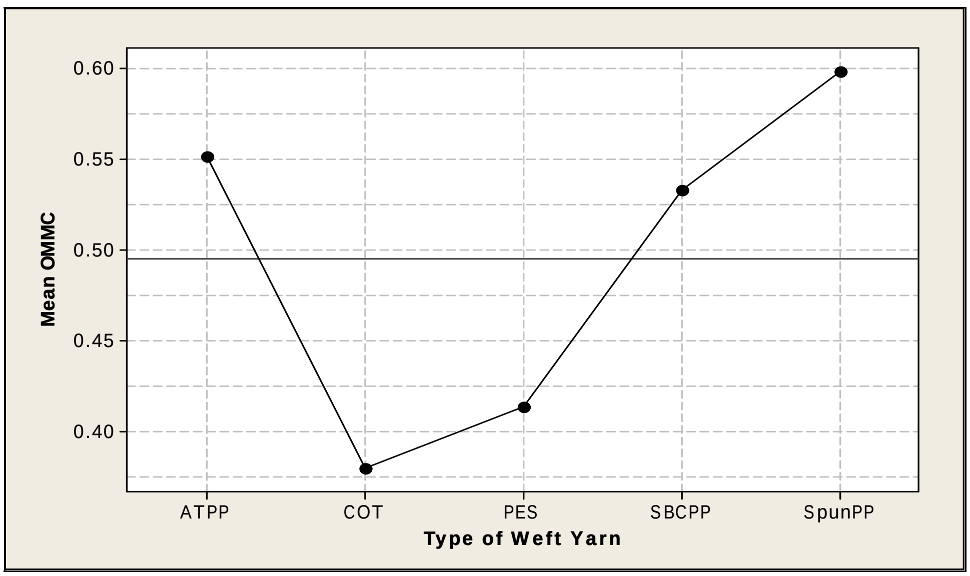

FIGURE 11. Effect of different types of weft yarns on OMMC.

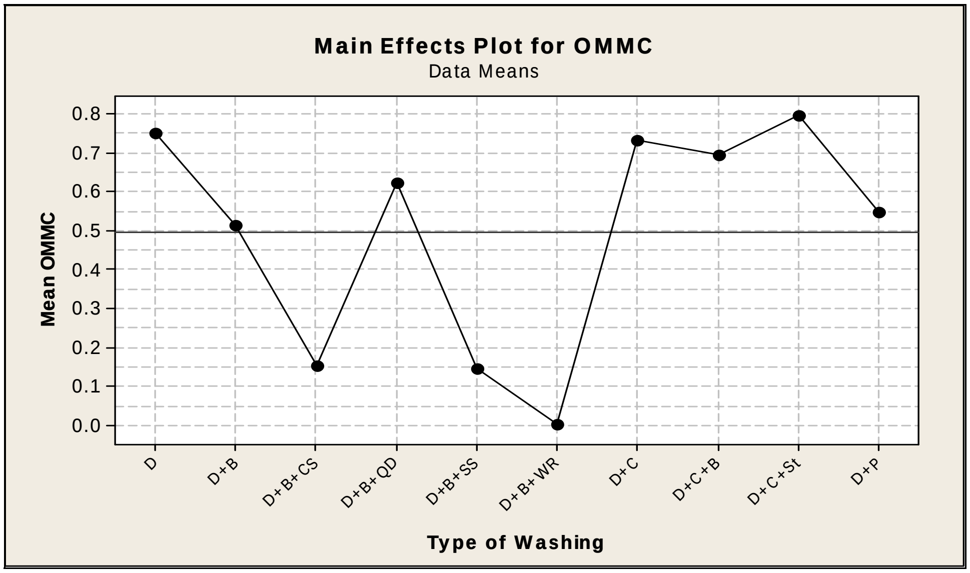

FIGURE 12. Effect of different types of washing treatment on OMMC.

CONCLUSIONS

On the whole moisture management capacity of denim fabrics is significantly affected by unlike types of weft yarns and washing treatments. Fabrics with pleasurable moisture management capacity can be developed by using a blend of hydrophilic and hydrophobic yarns in the fabric in such a way that the hydrophobic yarns are predominantly present on one fabric side, which would come directly in contact with the skin and the hydrophilic yarns are predominantly present on the other fabric side. Use of hydrophilic and quick-dry finishes can further enhance the overall moisture management capacity of denim fabrics.

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